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ABSTRACT

This document consists of three papers which explore aspects of language use in science classrooms descriptively and prescriptively, based on naturalistic and experimental observations. The discovery of the importance of the verbal mode of communication through involvement in creating computer-based activities is discussed. Papers include: (1) "Words and Science" (Jan Hawkins and Laura M. W. Martin), in which the thematic questions that tie the papers together are outlined; (2) "Taking Notes and Taking Note of Physics" (Babette Moeller, Jan Hawkins, Cornelia Brunnmer, and Sol Magzamen), in which words are regarded as a contributing medium to achieving understanding of physics concepts; and (3) "Computer Networking and the Connection of Science and Literacy Skills" (Shelley V. Goldman and Carol Reich), which reports on a study of language and communication in a classroom of deaf students. (CW)

BANK STREET COLLEGE OF EDUCATION

CENTER FOR CHILDREN AND TECHNOLOGY

Literacy and the Science Classroom

AERA Symposium, March 1989

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LITERACY AND THE SCIENCE CLASSROOM

AERA Symposium, March 1989

Contents

FORWARD

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This collection of papers was presented at a symposium of the same name at the annual meeting of the American Educational Research Association in San Francisco, in March 1989. A fourth paper from that symposium, *Discourses on the Seasons* by Sarah Michaels and Bertram Bruce, is available as a technical report from the Educational Development Center.

The aim of the panel was to explore aspects of language use in science classrooms descriptively and prescriptively, based on naturalistic and experimental observations. Each of the authors has been involved in creating computer-based activities for facilitating scientific inquiry in elementary or middle-school classrooms. Each of us discovered that the verbal mode of organizing information was a central issue in our projects. For Hawkins and Martin, and for Moeller et al., words were regarded as a contributing medium to achieving understanding, with their own constraints and affordances. In the case of Goldman and Reich, language and communication was the dependent variable in the classroom of deaf students in their study. The thematic questions that tie the papers together are outlined in Hawkins and Martin. It can be seen that despite common questions, the methods and approach of each project to the topic of language and scientific understanding in children were unique.

WORDS AND SCIENCE

Jan Hawkins and Laura M. W. Martin

Center for Children and Technology

Dissatisfaction with "textbook science" has grown over the last two decades in favor of "hands-on" and "minds-on" approaches to learning. As part of the redesign effort, science programs and curricula have correctly placed emphasis on ways to help students understand and use dense symbol systems such as formulas, graphs, and diagrams as tools of technical literacy. Literacy with verbal systems has received less attention as part of the activity-oriented approach to science.

This paper raises questions about the place of literacy in supporting the development of children's understanding the physical world. To answer them, we take literacy to be a psychological activity that occurs within the system of the classroom. Rather than approach it as a matter of text or speech processing, we view it in relation to how students and teachers communicate, how children respond to canonical information, and how school goals relate to real-world goals.

Science in classrooms is, to an extent, an oral culture. When children encounter information without notation or records—as in lectures—the teacher's spoken version of science interacts with children's ideas in unpredictable ways. A variety of different and erroneous ideas may be constructed by children and never fully articulated or understood by either children or teachers. Similarly, traditional kinds of written expression may keep children's own ideas and the science material isolated from each other. Reading textbooks, copying data, filling in worksheets, answering fact-based questions have been said to be antithetical to goals of inquiry learning because they don't allow children to begin with their own experiences, and they are relatively passive ways of acquiring information.

But the everyday investigative tool with which children and teachers come equipped is language. Through words in science, students work out conceptualizations and communicate about them. Words are necessary to form and reform questions, and words are a primary way to specify, confront, integrate, and transform ideas. Communicative skills can deepen children's reflection on and discovery of the natural world.

What are the some of the consequences of this view for goals and activities in schools? First, the verbal mode can be seen as a bridge between the everyday experience of phenomena and formal scientific understanding. Second, students can learn to interpret text-based information and to integrate it with knowledge gained through experimental and observational activity-based learning. Third, students can be helped to learn the literary modes and forms of scientific inquiry and about the communicative world of scientists.

Our illustrations of how a focus on literacy works as part of science learning grow out of two different research projects. In one, Inquire, a set of computer-based cognitive "tools" for supporting inquiry science with middle-school students was developed and investigated. Practically, it helps students accomplish individual or small-group science project work. Although mathematical tools are incorporated, the system relies heavily on text for representing the parts of inquiry work to students, and as the medium they use to record and interpret ideas of their own and others. It thus encourages representation and refinement of ideas in language, and verbal interpreting of material from multiple media (video, simulations, and experiments, as well as texts sources).

The other project, Linking Science and Literacy, developed and examined computer-based science literacy activities with upper-elementary school children. A variety of experiences were organized to motivate the children to write about science matters and to conduct other kinds of investigations. The study examined how teachers were able to make links to the students' questions and how children represented their experiences, both spontaneously and with instruction.

In brief, we saw that, first, the normal representation of "problems' for students is in language expression. These descriptions are recognizably their own, and they support intuition and observation. Making use of this verbal mode can draw students' attention to the articulation of their own ideas and the relationship of their understanding to the way teachers and others understand things.

In the first module of the Inquire software, students generate questions and lists of their own ideas about a topic as a way into a problem region, in this case sports physics. As they worked on these problems, students made use of a variety of information in multiple media (video, simulations with graph outputs, charts and graphs, as well as a variety of text-based sources). Students kept their records and formed interpretations primarily in language (e.g., hypothesis generation and justification). This requirement enabled students to relate the scientific formulation of ideas to their own ideas through revisions in their question-generation work. In formulating and justifying their conclusions, students had to review all their records, and summarize and integrate them. The encouragement to review, revise, re-see previous work-in-language helped students to construct their own bridges between articulation of their own ideas, and new information.

Language also served to help children notice their own learning and to think schematically. In the Literacy project, we encouraged children in their use of descriptors, which was at first quite limited. As they played games that promoted verbal elaboration and variation, children's discriminations about what they were observing heightened.

As they saw and heard the list of terms they produced, the children noticed their own perceptiveness. When we conducted a lesson designed to have students discuss their inferences about partially identified objects, a bottom-track fifth-grade class showed their cleverness and conceptual sophistication and, best of all, remarked on it themselves.

Second, we saw that children may have trouble holding multiple points of view in mind at once and integrating information from multiple representations. Working in groups maintains simultaneity of viewpoints, but common expression or referencing is necessary. The same student, furthermore, may express different understandings of the same event depending on the mode of expression.

Many of the Inquire procedures required students to record their own ideas and information they found from other sources in language. A striking example of the value of this was the use of verbal frameworks to interpret the meaning of graphs and charts. Graphs and charts have been shown to be particularly difficult and dense representations of information for students. As one part of their information search in a sports physics problem, students were required to interpret in writing the meaning of different parts of physical motion graphs generated by a microcomputer-based laboratory. These written records made misconceptions explicit—which could then be worked with—and directed students to different parts of the representation than they would normally attend to (e.g., slope), making the graph information available in a new way for integration with material from other sources.

Third, students need experience with the communicative forms of scientific work. They should be organized as communities of inquirers. Most school children are not used to collaborating academically except in discussion. Even then, the use of words is often not reflective or even particularly instrumental. Many teachers teach vocabulary first in a science unit in order to get the children "into" the subject, but there are prior lessons about language in science that can be developed. In the literacy project, we organized communication games about science content to help demonstrate why scientists use specialized vocabulary. In the exercises, others' actions depended upon the player's choice of words so that the power of using selective language became vivid.

Using others as a source of information, for instance through interviewing, is also a useful lesson, although it takes practice. Children have a sense of people as sources already. Organizing questions and comparing answers is a new skill related to more abstract ones used in advanced research. We saw that learning how to reduce and report on verbal information as opposed to visual experiences is also a powerful lesson for children because it gets them to think about data representation very intuitively. They quickly see that they can't replay the interview tape each time someone wants to know what they found

out. Instead, they begin to devise ways to condense and communicate the essence of the information.

Activities that focus on literacy aspects of science can be fundamental sources of links between a child's own world—inner and outer—and a more systematic organization of experience. While many of the benefits of speaking and writing are taken for granted in school contexts, such activities can be a deliberate instructional tool in the science class. They are powerful both because they begin with natural forms of expression and because they allow us to go beyond referential, practical communication to a plane of communication that is inferential, patterned, and imaginative.

TAKING NOTES AND TAKING NOTE OF PHYSICS

Babette Moeller, Jan Hawkins, Cornelia Brunner, and Sol Magzamen
Center for Children and Technology

INTRODUCTION

An important aspect of doing science, whether for scientists or for young students learning science in school, is to gather, integrate, and interpret new information. For young students, this task is becoming more complex as science education is moving away from a predominantly "textbook-based approach" to learning, and as different kinds of technologies and media are becoming available in schools. The information students encounter in today's science classes can originate from such diverse sources as hands-on experimentation, texts, graphs, tables, computer programs, observations, films, videos, lectures, and conversations with peers and experts. Because of differences in the format and quality of such information sources, the task of analyzing and synthesizing information can be very difficult.

The production of written language, or more specifically written notes, can serve as an important analytic tool in this task. Note taking is a special activity that not only allows students to keep records of new information, ideas, and thoughts, but has other advantages that make it particularly useful for helping students to interpret and integrate different kinds of information. First, the transformation of a variety of experiences and kinds of information into written language allows students to refine the meaning of this information and to reflect on it. Second, through the process of note taking, different kinds of information are translated into one unified symbol system (i.e., written language), which may facilitate the process of relating and integrating information that originates from different media. Third, by having external written records of new information, ideas, and thoughts, these pieces of information can be more easily manipulated.

The production of written notes, though, is itself a difficult activity. As research on note taking has demonstrated (e.g., Brown, Bransford, Ferrara, & Campione, 1983; Hidi & Klaiman, 1983), young students, if they take notes at all, often tend to rely on unreflective note-taking strategies, such as verbatim copying of information. Most of this research, however, has focused on the ways in which students derive notes from written text. Little is known how and the extent to which students take notes on information sources other than text.

This paper reports the results of a study in which we asked a group of middle-school students to take notes on information from multiple sources in the context of solving a science problem. This research allowed us to investigate the ways in which students interpret different types of information in their notes. In addition, we were able to examine the extent to which note taking contributes to students' understanding of new materials.

THE STUDY

The research on note taking was part of a larger study that examined the effects of a software program called Inquire on students' learning of science concepts and skills. Inquire is a prototype software system that has been developed at Bank Street College to support students' inquiries in science. The software provides students with a set of analytic tools that allow them to refine, analyze, and revise qualitative and quantitative information. A central part of this program is an "information module" that provides structures for students to record, identify, query, and manage information.

The participants in the study were seven sixth graders between the ages of 11 and 12 years. The students worked individually, in six one-hour sessions, on a science problem using the Inquire system and content materials in multiple media. The science problem that guided students' inquiry was taken from the domain of sports science. Students were

asked to select individuals from a team of runners as entrants in a 100- and a 200-meter race, and were required to justify their selections "scientifically." The problem required students to understand and recognize the value of three different kinds of information: the physical science factors involved; the ways in which the two races differed in their performance demands; and the critical qualities of the runners. The central concept that organized the problem, and that students had to learn about in their inquiry, was the concept of "acceleration."

For the inquiry problem work, students were given a variety of materials to work with: (l) a 12-minute video episode illustrating and explaining aspects of movement in animals; (2) different kinds of texts about motion concepts, which included a physicist's account, a coach's account, and a newspaper article about motion on the moon; and (3) data in the form of tables and graphs about runners' characteristics and performances (see Figure 1).

Students were presented with the video and the texts, as well as the runners' tables and graphs, and were asked to take notes using the Inquire system. While the students were asked to use all of the materials, it was left to them to decide whether or not to take notes on the different materials. The students spent a total of two sessions reading, watching, and interacting with the materials and taking notes on them.

Another procedural element in our study was a pre- and post-test. These tests were included to assess changes in students' understanding over the course of the study. In the pre- and post-test, we examined students' understanding of the concept of acceleration in a variety of contexts. First, students were asked to produce a voice-over narration for a video episode from the 1936 Olympic sprint of Jesse Owens. In a second task, the students were asked to draw graphs of the runners' performances and explain graphs by others. Third, students were given a standard physics

Type of Source	Description	Reference
Video	12-minute segment that compares animals' (human and non-human) ways of running	Boswall, J. (producer, writer). (1981). *Animal Olympians*. Boston, MA: WG3H.
Texts	1. A physicist's account, examines the concept of acceleration in the context of running	Brancaslo, P.J. (1984). *Sports Science*. New York: Dodd, Mead.
	2. A coach's account, explains different running techniques and requirements of different races	Sullivan, G. (1981). *Better Track for Girls*. New York: Simon & Schuster
	3. A newspaper article, explores how runners would run on the moon	Brancaslo, P.J. (Sept. 10, 1987). *Sports on the Moon*. San Francisco Examiner, 9/10/87
Tables	1. Data on sprinters' abilities (maximum speed, endurance, reaction time, trainability) for each of 11 runners	Inquire project, Bank Street College of Education
	2. Data on sprinters' acceleration (distance run and speed reached at eleven one-second intervals during an 11-second training sprint)	Inquire project, Bank Street College of Education
Graphs	1. Speed-time graph for each of the 11 runners	Inquire project, Bank Street College of Education
	2. Speed-distance graph for each of the 11 runners	Inquire project, Bank Street College of Education
	3. Distance-time graph for each of the 11 runners	Inquire project, Bank Street College of Education

Figure 1

problem concerning differently sized blocks sliding down an inclined plane, asked to predict what would happen, and then to explain what they observed. The post-test included two additional video segments, one showing a cheetah chasing prey, and the other a race car driver who experienced rapid acceleration and deceleration. The students were asked to provide scientific explanations of the motions they observed in these events.

RESULTS

Spontaneous Note Taking

The notes produced by the students using the video, the texts, and the runners' graphs and tables served as the main data source for our analyses. These notes were on the average 393 words long (with a range of 127 to 556 words).

The first question with which we examined these notes concerned the amount of notes students produced for each source. Figure 2 shows the percentage of notes that were derived from each of the different sources.

The data indicate that there were dramatic differences in the extent to which students made use of different sources in their notes. The students derived the majority of their notes from the texts, followed by the video, and then the tables and graphs. On the average, 84% of the notes were derived from the texts, 9% were derived from the video, and 7% were derived from the tables and graphs. The same ranking of the sources is obtained when we compare the number of students who used the different sources for their notes. All seven students produced notes based on the information presented in the texts, six students took notes on the video, three students derived notes from the tables, and only one student took notes on the graphs.

While these differences in students' utilization of various information sources are interesting, there are many factors that could have contributed to them. The sources differed not only in the way information was presented, but also in the kinds and amounts of information that were contained in them. We decided to extend our analyses to examine whether there were any differences in the note-taking strategies students employed with different kinds of sources. For this purpose, we proceeded to analyze the content of students' notes in terms of how information was summarized and integrated. We will discuss the results for the notes from each of the different sources in turn, beginning with the video notes.

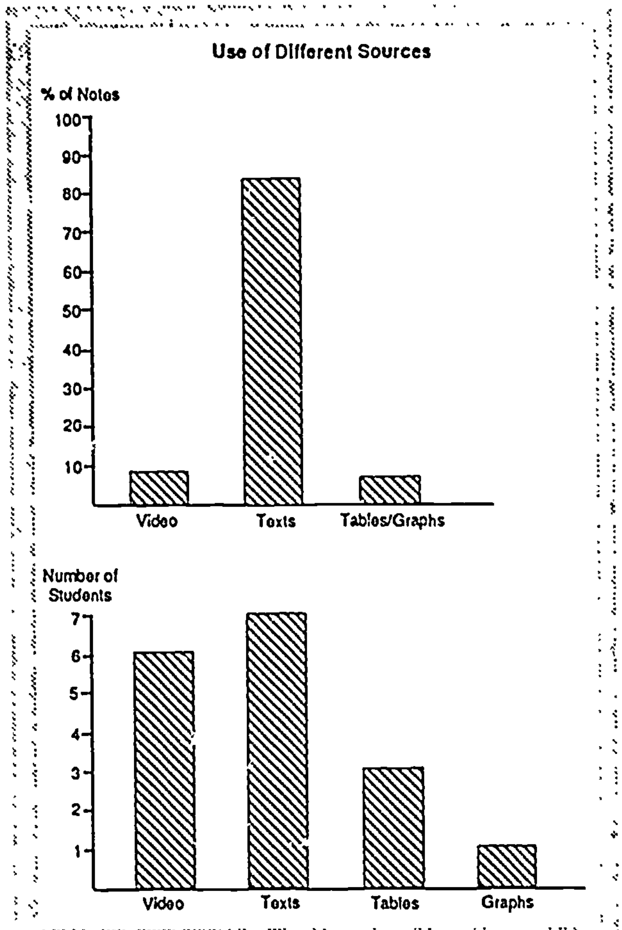

Figure 2

Even though the notes that students derived from the video are relatively brief, they reflect a surprising sophistication (see Figure 3a). All six of the students who produced notes from the video included statements that either summarized whole episodes of the video (21% of the notes) or statements that integrated particular pieces of information across different episodes of the video (38% of the notes).

The remaining 41% of students' video notes consist of paraphrased statements of details that were derived from the voice-over narration of the video. Interestingly, notes taken on the video focused predominantly on the narration rather than the visual images. Only one student made a statement in his notes that was clearly derived from the images alone (i.e., "It looks like people push off on the front part of their feet").

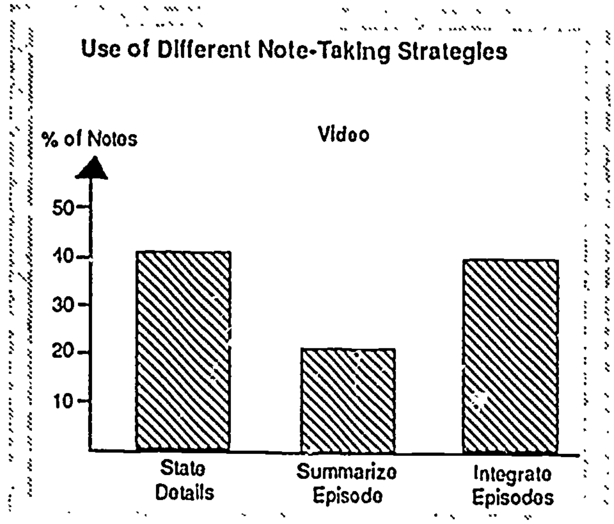

Figure 3a

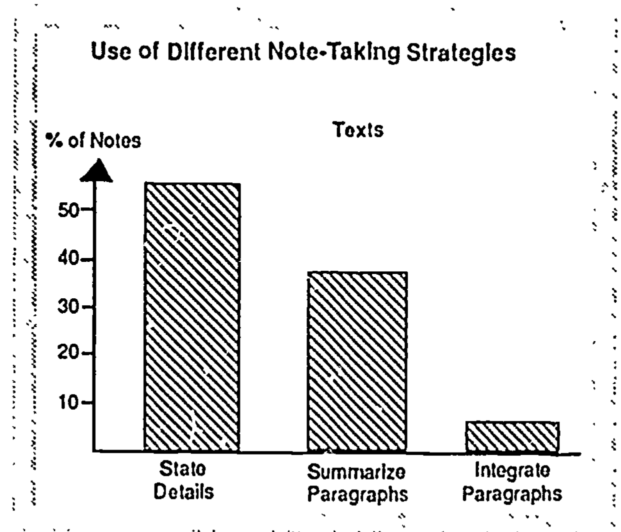

Figure 3b

The students were selective in terms the information they included in their video notes. Rather than following the strategy of summarizing the whole video sequence, students appeared to selectively record information they considered relevant to the science problem they were working on. They organized at least some parts of their notes around information that was relevant to the physical science factors involved in running, the performance demands of different races, and/or the qualities of the runners.

The notes that students derived from the texts differed in several respects from the video notes (see Figure 3b). First, students showed a stronger tendency to copy their notes verbatim from the texts. On the average, 34% of students' notes were copied verbatim, while 66% of the notes were paraphrased. In addition, students were not quite as successful in integrating information within or across segments of the texts as they were in dealing with the video.

On the a rage, 56% of students' notes consisted of statements that were derived from low-importance detail information (e.g., particular examples) in the text The remaining notes consisted of statements that integrate information within a paragraph (37%) or across paragraphs (7%). The organization of students' text notes followed the linear sequence in which information was presented in the texts. Even though the students produced notes on the kind of information that was relevant to the science problem, such as the physical science factors involved or the performance demands of the different races, none of the students organized his or her notes around these issues.

Finally, the notes students derived spontaneously from the runners' tables and graphs reveal yet another kind of note-taking strategy. These notes consisted of students' inferences about the information presented to them rather than summaries of the information. All of the students who produced these notes listed the names of preferred runners and noted justifications for their selection, making reference to important physical science factors. Hence, when taking these kinds of notes, students not only summarized but interpreted the information within the context of the science problem they were solving. In addition, in making their interpretations and justifications, they integrated the information presented in the graphs and tables with information they had previously encountered in the video and the texts.

In summary, we found not only quantitative differences in the way students derive notes from different sources, but also qualitative differences in note-taking strategies. Text-based materials elicited a great deal of note taking from students, but their notes revealed little evidence of information integration or interpretation. The reverse was true for the video and the tables and graphs. While students took relatively few notes on these materials, they engaged in more integrative and interpretative note taking. It is interesting to note that the sources represent different points on a continuum from the most linguistically based information source to the least linguistically based information source. Our results indicate that the less linguistic an information source is, the less likely students are to take extensive notes on them, but if they

do, they tend to employ the more sophisticated note-taking strategies.

Pre-/Post-test

In our final analyses, we examined whether the progress students made in their understanding of the concept of acceleration and their note-taking strategies were related. According to our pre- and post-test measures, all of the students made some progress in understanding the concept of acceleration in different contexts. Some students, however, advanced considerably more than others and we were interested in seeing whether differences in note taking could be detected for those students who made considerable progress, compared with those students who made less progress and displayed lower levels of understanding on the post-test. The students were divided into two groups—a high- and a low-progress group—based on their change scores between pre- and post-test and their mean post-test score. There were three students in the high-progress group (one girl and two boys), and four students in the low-progress group (two girls and two boys).

We found interesting differences between the two groups of students (see Figure 4). First, the students in the high- and low-progress groups differed in the overall amount of notes they produced. The students in the high-progress group tended to take fewer notes (on the average, 334 words long) than the students in the low-progress group (on the average, 437 words long). In addition, even though the notes of the high-progress students were shorter, they managed to include information from a greater variety of qualitatively different sources compared to the low-progress students. All of the students in the high-progress group derived their notes from the video and the texts, and two of the students in this group also produced notes on the tables and graphs. Only one of the low-progress students used the video, the texts, and the tables as sources. The other students in this group used either the video and texts or the texts only.

We also found that students differed in the extent to which they integrated information in their notes. Overall, the notes of the high-progress students reflected more information integration within and across segments of the information sources than the notes of the low-progress students. On the average, only 43% of the notes of the high-progress students consisted of statements of details, as compared to 51% of the notes of the low-progress students.

Use of Different Sources

Students		Video	Texts	Tables	Graphs
"High"	1	19%	59%	4%	18%
	2	6%	70%	24%	
	3	19%	81%		
"Low"	1	8%	92%		
	2	21%	70%	9%	
	3	7%	93%		
	4		100%		

Comparison of Note-Taking Strategies

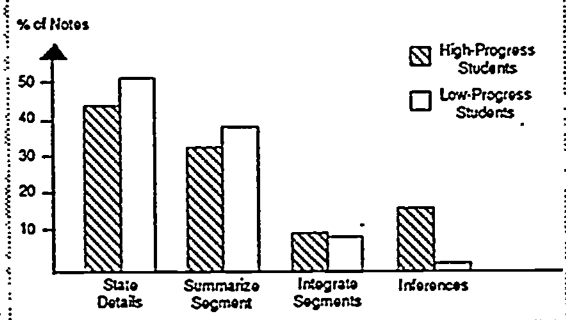

Figure 4

These results suggest that the way in which students produce notes is indeed related to their understanding of the materials they are working with. It appears that reflective note taking that utilizes multiple information sources may *contribute* to the understanding of new information.

DISCUSSION

In conclusion, we would like to address some of the educational implications of this research. An important point to be made at the outset is that the production of written notes per se does not guarantee better understanding of new information. Our research suggests that if students use note taking as a mere transcribing (or copying) exercise, it contributes very little to their understanding of new materials. In order for note taking to be helpful for students, it needs to be used in a *reflective* manner.

Why do students often fail to use note taking in such a way? Our research suggests that students do not altogether lack the ability to use reflective note-taking strategies, but that their note-taking strategies depend on the context of the activity and how they

interpret it. It appears that students predominantly interpret note taking as a transcribing exercise rather than as a reflective activity that could be helpful to them. Traditional media such as texts and oral language are most easily recognized by young students as sources for written notes. The linguistic nature of these materials makes them most compatible with a transcribing approach to note taking. Nonlinguistic information sources, on the other hand, are not as easily recognized as sources for notes, very likely because these materials do not lend themselves to transcription or copying (at least in a written form). If students utilize these kinds of sources to derive notes from them, their note-taking strategies necessarily have to be more reflective, since the transcribing strategy does not work.

For students to use note taking in a more meaningful and efficient way, they need to learn to appreciate the reflective nature of the activity. There are multiple ways in which this can be accomplished. An important element in such efforts should be to deemphasize the transcribing function of note taking and to emphasize the reflective aspects of the activity. One way in which educators could engage students in more reflective note-taking strategies is by encouraging them to take notes on a wide variety of information sources. This would allow them to practice reflective note-taking strategies in the context of nonlinguistic sources. In addition, reflective note taking could be supported by providing students with guiding questions for their notes. We carried out such an intervention in our research.

To help students interpret a series of graphs that they produced with an electronic motion detector (TERC), we asked them to take notes about the meaning of each graph, as well as to compare pairs of graphs. The intervention turned out to be quite successful. All the students actually took notes on each of the graphs, and most of their notes contained interpretative elements rather than just descriptive statements.

Another way to promote reflective note taking, especially with text materials, is to encourage students to produce "notes on notes." By structuring their note taking into a two-step recursive procedure, students may learn to distinguish between note taking as a record-keeping tool and note taking as an analytic tool.

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COMPUTER NETWORKING AND THE CONNECTION OF SCIENCE AND LITERACY SKILLS

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INTRODUCTION

We have been studying the possibility of enhancing both literacy and science skills among deaf students by engaging them in purposeful science learning using a local area computer network. We use the term "literacy" to refer, most obviously, to any engagement with print (reading and writing) and, less obviously but just as relevant, to activities that lead to engagement with print (e.g., conversation around print, practice at particular language skills). We report on some tentative results of research on the ways literacy work and science work were present and related in computer-networked Earth Science classes at the Lexington School for the Deaf.

There are two points to the paper. First, in actual classrooms, literacy and science work were overlapping and mutually constitutive of activities and lessons. A tremendous amount of focused classroom interaction went into discussions of new words, the ways in which to include them in sentences, and the struggle to get them written down. Although our data come from classrooms for the deaf, for whom spoken and written English can be difficult enough, we believe this can be the case in many science lessons.

If we are correct, literacy work is at the core of classroom science work and must be made a more obvious part of the science curriculum. Further, we can rely more on important subjects such as science to educate students who are having trouble with literacy skills. There is no reason, for example, that deaf students should be deprived of science lessons because spoken and written English come slowly to them.

The second point is that the computer-networked classroom organizes interactions that are educationally productive. This is the case, first, because the network highlights the literacy work embedded in the science lessons. Students must write everything down on the network. Not only does this give them much time on task in both literacy and science, but our data indicate that it also encourages teachers and students to attend to the various reading and writing devices they need in order to do the science work. Second, the network is a resource for powerful pedagogy because it allows for so much conversation among the children.

We are excited that from our first intuitive overview of the data, the network seemed to establish the social and conversational grounds for both literacy and science to be accomplished. The children were on task, and the tasks became part of the fabric of the interactions among all the people in the classroom.

Our data fo identifying these connections come from observations of more than 75 science classes, open-ended and structured interviews with teachers and students, videotapes of networked and non-networked science classrooms, collected written science materials and products of assignments, and a corpus of more than 2,500 electronic mail messages generated on the network. We conducted several preliminary analyses of electronic mail usage and function, an analysis of student writing, and an analysis of patterns of interaction in networked and non-networked science classrooms (Goldman et al., 1988). The complimentary findings from each of these analyses contributed to our conclusions.

We discuss our conclusions by taking the following steps. For the remainder of this introduction, we provide background information about the problems deaf students face inside classrooms, the evolution of our research collaboration, and the level of our stu-

dents' hearing impairments. This information helps to familiarize the reader with our goals and provides a backdrop for the discussions and examples of student work that follow. We then present the relationship between science and literacy work as we saw it through our different analytic lenses. We start with an example of how a typical networked lesson required students to practice both literacy and science skills. We then look at two ways that the science teachers developed lessons on the network. One teacher used the network interactively with students to conduct content review sessions, while the other teacher used the network as a tool for adapting textbook materials in order to reduce the students' language barriers. Each method for using the network increased students' participation in lessons and completion of assignments. Finally, we describe briefly the qualities and processes in students' networked writing that indicated a rich emergence of literacy around science. Taken together, the three discussions allow us to see how lesson planning, learning needs of students, and the resource of a technology interacted to define literacy-rich science activities. We conclude by discussing the ways in which networked interactions are worthwhile developmental activities.

Background of the Problem

There is an urgent need to improve science and literacy education in America (National Commission on Excellence in Education, 1983; NRC, 1985; NSBC, 1983). Evidence from cognitive and educational research suggests that to foster an understanding of science that will develop a science perspective and body of knowledge, motivate further interest and learning as well as transfer to situations outside of school, science instruction should permit students to participate actively in science learning. Children should engage in inquiry activities and ask questions as they conduct hands-on scientific investigations (Kyle, 1978); work collaboratively with other students (Riban, 1976; Slavin, 1983; Webb, 1982); and make connections between their understandings of science, other aspects of their school work, and familiar events in the world (Hurd, 1986; Jackson, 1983; NCEE, 1983).

These conditions are rarely established in science classrooms. These problems are exacerbated for deaf students, since 90% of deaf children are born to hearing parents and don't have a language base when they enter school. Much school time is spent learning language as an activity in and of itself. Limited literacy contributes to keeping the deaf out of both the mainstream of education and subjects like science that have specialized vocabularies, processes, and perspectives. Deaf children who graduate from high school have, on the average, reading skills below the fifth-grade level (Allen, 1968).

Taken together, this information suggests that it is not simply what students learn that must be changed, but that the processes of teaching and learning in science classrooms must be altered. To improve the literacy and science learning problems of deaf children, one would need a learning environment where science skills and language skills were not disembodied school activities, but situated in the flow of purposeful learning. Science learning would involve students' communicating with a number of audiences, including classmates, teachers, and hearing students. We attempted to establish such an environment by using computer-network technology.

History of Collaboration

Aware of the need for new kinds of learning environments, the Lexington School for the Deaf began to emphasize students' use of language and communication as a means of accomplishing purposeful school activities and real-life tasks. Bank Street College and Lexington Center began to collaborate in finding ways to enlist new technologies for creating improved communication environments inside school where reading and writing could become natural conversational forms of communication for intellectual and social purposes. Literacy Network was founded as part of that larger effort because there was evidence that computer networks could support this kind of environment. Networks link computers so that a person at one machine can communicate and share information with a person at any other machine on the network. Our hope was that by using a local area network technology, students' reading and writing work would not be disembodied activity, but would become an essential part of purposeful learning activities in other curriculum areas. Additionally, we hoped that students would develop a sense for communicating with different audiences, including classmates, teachers, and students in other schools.

A network called Earth Lab, which was developed at Bank Street College and showed promise as a communication tool, was introduced in two earth science classes at the Lexington School in February 1988.[1] Students in high school earth science classes

participated in the network project. All of them had a profound hearing loss in excess of 80+ dB. Basically, the students could not hear closing doors, footsteps, or sounds in the normal speech range. That meant that many events, including those in classrooms, shad to come into awareness through the visual channel. Teachers and students used sign language, lip reading, and a variety of visual aides in order to communicate during lessons. The local area network technology infused the classroom communication scene with a reading and writing channel, allowing for new ways to receive, process, and hold on to information.

SCIENCE AND SITUATED LITERACY

Literacy Situated in Science Lessons

When we analyzed observational data, we were struck by how much literacy skills were attended to in the process of accomplishing science work. There were two main findings in this area of the evaluation. The first was that literacy work and science work were overlapping and mutually constitutive of networked lessons. This is important because while we recognize that literacy is always important, we often ignore its presence as a foundation of the work in the curricular areas. The communication needs of deaf children make the need for recognizing the literacy underpinnings of science work all the more obvious. This makes a strong statement that we might need to concentrate on how we orchestrate literacy in our science lessons and, correspondingly, expect that our students might learn more science as well.

The second finding is that networked interactions are worthwhile developmental literacy activities. The network helped students work on literacy and science as mutually constituted problems and provided a social context within which both could be accomplished.

In what ways did the networked science classroom provided a rich environment for literacy learning? When students went "on line" for science they, by necessity, had to read and write a great deal in order to communicate about their ideas and the procedures they were following. Completion of the science lessons demanded constant attending to reading, writing, and spelling. The students became submerged in a print environment from the time they logged on, received a greeting from the teacher, and were given directions for the day's activities to the time they sent work back to the teacher for feedback and printed a copy of the assignment to take home. An example of a typical networked lesson helps to illustrate this mutual construction of activities.

> The students were working in a unit on rocks and minerals. After studying minerals, students were asked to identify minerals by their specific characteristics. They used a teacher-created database on the network for the exercise. Each student was given a sheet of paper with "clues" to help them in the search for minerals. A clue might read. "My color is black and my hardness is 5." Each clue gave the students a combination of information about a mineral that distinguished it from all of the others. If students picked out the pertinent information and then used it to search the database, they would retrieve one mineral data card from the corpus. Done correctly, they would identify the mineral with certainty. If students chose the wrong or irrelevant information from the clue or if they constructed an unacceptable sentence for searching the database they would not be able to isolate the mineral they needed to identify. In that case, they might retrieve several minerals (e.g., all minerals with a hardness of 5). If that happened, the students would have to browse through each of the records that were pulled from the database, and then skim several records in order to match the information in the clue with the information on each mineral record (i.e., is this mineral black?). The "browse" method was chosen by many of the students, although it was the less efficient way to complete the task. When the teacher noticed that the students were browsing, she stopped the activity and announced that she was requiring the students to identify the two or three pieces of relevant information in the clue and construct a search that would turn up only the correct mineral record.

This activity was literacy intensive. The stated science-related goal of the activity was to help students become more familiar with the characteristics of minerals and to learn how those characteristics are used to identify minerals. Although unstated by the teacher as a set of goals, the students' activities were literacy-skill intensive. Students had to read for the most important information, identify the categorization system and the names of the categories, and construct full and often complex sentences. This sentence construction task required the employment of categorization schemes and the use of skills that deaf students needed practice with, such as using articles

and conjunctions. Even the browsers did a great amount of literacy work. They were, in fact, practicing the skill of skimming for the relevant information. These particular literacy skills were evident in each of the database activities conducted during the study. The irony in this is that the science teachers stated often that they needed to concentrate on science learning and had little time to spend on language skill remediation. They did feel that students' language needs hampered the progress made on science learning, but felt those problems should be handled by other teachers. Their view was perfectly consistent with the way the school was organized, given that the students spent a high percentage of their elementary school years learning language skills.

We highlight this set of activities because they are representative of a basic problem in education and a corresponding solution in the network. Literacy was the warp around which the science activity was woven. This was mostly ignored even when the very literacy skills being demanded were the skills that the students were lacking. We were delighted to see that our networked lessons made the practice of literacy part of purposeful learning activities.

Teacher Use of Electronic Mail

The decision to pursue a network was based in part on the hunch that it would increase students' participation in written English, and in part to provide a new environment for science learning. The science teachers received training to familiarize them with the network and the kinds of activities it might support. They eventually used the network to organize a range of assignments and activities. Electronic mail became the application of choice. Electronic mail was used to give instructions and directions; carry on class discussions; complete assignments, tests, and science writing tasks; and give feedback and evaluations. Each of the teachers developed ways to use the network that matched their classroom goals and personal preferences and styles. Each used the network in a way that brought literacy work to the forefront of science learning activities.

One teacher used electronic mail interactively with students as a review device for test preparation. Students received a set of review questions over the mail system and set out to answer them. During class time, the teacher sat at a terminal to collect her mail and respond personally to the students' answers. This allowed the students to work independently and at their own pace, while making timely responses from the teacher possible. All students participated fully in the networked review exercise, which was unlike the patterns for face-to-face classroom discussions where it was usual for only a couple of students to participate actively in responding to a question (Goldman et al., 1988). In addition, students could print out a record of the entire question-answer-clarification interaction and use that information to study for their test. The ability to print out was welcomed by students who had the problem of missing entire segments of the signed discussions while they were looking at their notebooks and writing notes.

The other teacher used electronic mail to present modifications of the state-mandated science texts to the students. She modified the language level of the texts to make them more readable and consistent with the language level and presentation style used in her written materials and classroom lectures. With the text and assignments on the network, she felt she was able to better assess the students' understanding of science information and concepts. This turned out to be significant because, with this method, students were not hampered by their restricted accessibility to language and completed three assignments in the same time they previously completed only one. The results were impressive. The print environment increased the students' productivity by minimizing language discrepancies and allowing them to spend more time interacting with science concepts.

Analysis of Electronic Mail Writing

Lessons on the network also encouraged students to write a great deal. They completed many kinds of writing in response to assignments and social requests. They wrote daily science journals, completed worksheets and assignments, reviewed for tests, typed homework, and had written social and academic exchanges with their fellow students. Many of the activities featured dialogic interactions between students and teachers, such as responding to the teachers' questioning, recounting events, and creating event casts and stories. In these interactions, students used writing to make requests; negotiate behaviors; investigate; communicate information; express opinions; evaluate themselves, their writing, and their classroom activities; accomplish social goals; and create fantasies. These kinds of interactions are present in the language development of hearing children (Heath & Branscombe, 1984) and are encouraged in many

writing development programs (Graves, 1980).

The messages from electronic mail were analyzed to describe the development of the students' writing and to see if the network provided a forum for social interaction and science experiences. We looked specifically at how the different patterns of interactions and tasks around writing influenced students' writing.

We examined all of the writing that students sent on the network. Multiple samples of each student's writing were read to delineate features, find developmental pattern., and determine students' fluency. Eventually, we concentrated on studying features of writing that were part of communications with teachers or other adults, or writing that underwent revision processes. We found that the network provided opportunities for rich interactions around science to occur. The network also served as a channel for students to have conversations in written English. In general, the students showed an ability to control their ideas and content in their written work. They had problems at the level of the sentence with word order and the use of unstressed words.[2] At the level of the paragraph, students had difficulty in using literary cohesive devices (e.g., although, then, afterwards, while) and elaborating on ideas. The encouraging result is that students did organize their thoughts and used inventive ways to circumvent their lack of conventional English skills.

Our most promising developmental find was that the students used a variety of writing conventions and processes in these communications and often incorporated features of more experienced writers. Most of the networked conversations had a quality of "speech written down." Even so, students referred generally to initiating messages and wrote responses in full sentences. We saw frequent use of the vocabulary and structure of initiating messages in responses. One boy used the vocabulary of the question—What are two ways that clastic rocks form?—in the topic sentence, and then used numbers to organize his response:[3]

> There are two ways that clastic rocks form are (1) from the pressure in the ocean or lakes. (2) the cement—when the minerals in ocean water stay behind while the water evaporates. The minerals glue the rock pieces together.

Students tended to organize their responses by paragraphing, making lists, or utilizing "signal words" such as "first," or "next" to orient the reader. For example, one boy organized his response to "List the three classes of sedimentary rocks and the sediments that the rocks in each class is made of" by using three paragraphs to correspond to the three classes:

> Clastic rocks formed inside ocean beds and any water bodies that from fragments rocks became cement make two fragments of rocks together.
>
> Organic rocks formed on or inside crust that thousands years of fossils when dead plants and animals remain to broke into pieces of plants or animals. Also, inside water that sea animals died many years ago, their shells broke into pieces or remain on limestone's surface.
>
> Chemical rocks formed near bay or coast that two minerals mixed into rock when in water, it float to shore, and rock was evaporation action.

One girl responded to "Describe the two ways that clastic rock can form" by using "2 ways" to organize her thoughts:

> 1 way underwater pressure the rock together 2 way there 3 different kind of rock like calicat, halite and quartz stay in water when evaporate they became glue together

This indicated that the students benefited from the interactive nature of these written lessons. They ould elaborate on current skills and model new skills they encountered in the writing of others. For example, one boy responded to the Trivia Question, "Why do you think some baseball players put black lines under their eyes when they're playing ball?"

> the reason why the baseball player want the black stuff to put the eyes and it help the player to see the ball when it fly and it help to see better and it block the sun

We found that the network provided opportunities for students to communicate about science through reading and writing. The networked interactions also provided opportunities for students to work collaboratively with others in trying out new language skills.

The Relationship of Writing and Social Interaction

We looked specifically at how the different patterns of interactions and tasks around writing influenced students' writing outcomes. We concentrated on writing that was embedded in communications with teachers or other adults, and writing that underwent revision processes. Results of the analysis indicated some trends and generated some recommendations

about how to capitalize on the interactive nature of classroom science activities to encourage the practice of writing and writing skills. Improvement in the quality of student writing could not be evaluated properly. Current evaluation methods are unable to locate growth in writing development in the short period of time that constitutes a school year. In addition, the naturally occurring tasks of the networked activities defied standardization of writing evaluation tools. We were, however, able to identify emergent patterns: students' writing was better when they wrote to outside audiences, responded to teachers' questions and requests, and engaged in writing process work and revision processes. This meant that writing practice, and most likely writing development, was intrinsically tied to the kinds of learning activities that the students got to experience.

The network did provide a tool for writing to emerge in the course of doing science activities, and that makes the choice of selection and organization of activities all the more important. The science teachers will inadvertently be structuring literacy skill work for their networked students. Now there must be ways to design classroom activities that attain science goals and capitalize on activities and techniques for improving students' written literacy skills. We delineated some patterns in students' writing that were contingent on the pedagogical interactions with which the students were involved.

Writing that was part of a string of interactions rather than a result of a single assignment produced longer, more cohesive texts related to classroom content. When teachers responded in a timely manner to students' science journals or written requests, students produced more text and, often, more cohesive text.

Messages that asked questions of students generated the longest responses and often resulted in students clarifying ideas they had presented in an earlier correspondence. This worked similarly to revision techniques practiced in many writing process programs, which have demonstrated positive results. In general, students were quite responsive to the individual attention they received from their teachers over the network, and reciprocated accordingly by producing more text communication.

New kinds of communications opened up between students and teachers. Students wrote about their feelings to the teachers. They wrote about why they didn't like the way science class was going, and how they felt about the teacher's mood in class. Rarely do students have the opportunity for this kind of communication in the classroom. The science journal was the vehicle for this personalized writing. Often these journals were written by students using the network during their lunch or study periods. The quality and length of the journal writing varied and actually seemed to go up and down at different times during the school year. Journal writing improved in overall quality when teachers and students used the journals for conducting conversations with each other. Students did not initiate many questions inside their journal writing. But when teachers asked questions, they answered. In the instances when the journal became a vehicle for ongoing dialogues between teacher and student, it resulted in more eventful writing experiences.

Science teachers could capitalize on these trends by structuring journal requirements in ways that encouraged particular styles, lengths of texts, and topics to write about. In addition, the data point to the need for the teachers to converse electronically with the students on a regular basis. The journal has the potential to be a powerful tool for both science and literacy learning if it is attended to by teachers in a conscious way.

We found that more cohesive accounts were written when students communicated with outsiders. In several cases, this had to do with the fact that written work underwent lengthy revision processes; in other instances, the communications were with students and adults outside of the immediate science classroom. Science writing to expanded audiences showed more correctness and fluency. This suggests that students should be required to respond to each others' work, produce assignments collaboratively, and correspond with other adults and more expert writers.

SUMMARY AND CONCLUSIONS

Our analyses revealed characteristics of a new kind of communication environment that Literacy Network enabled in the science classrooms that make it a promising developmental environment for literacy skills in the long term. There was a great amount of literacy situated in science learning, and teachers were able to have more reliable information about where language barriers existed that impeded science learning or communicating about science information or con-

cepts. The interactions inside the science lessons had all of the features necessary for literacy development—communication and interactions between teachers and students based on developing higher order skills such as problem solving, categorization, and the expression of ideas.

Our preliminary analyses of electronic mail indicated that students have complex thoughts about science, although they communicate them in many forms of writing in many emergent stages. The following example illustrates that while this student is not yet a fluent user of written English, she can monitor her progress and ask questions about her complex ideas:

> HI AND I STILL LEARNING THE MINERALS BUT ITS HARDLY TO UNDERSTAND HOW CAN U EXPLAINING ABOUT HHOWW SCIENTISTS WERE AWARING ABOUT ROCKS FORM AND ALSO HOW CAN YOU EXPLAIN ABOUT HOW SCIENTISTS DISCOVERED THE MINERALS AND HOW THEY RESEARCHING THEM.

This student is thinking, expressing her ideas, and writing questions—all in the area of science. Her questions to her teacher moved beyond the boundaries of the curriculum. She questioned the work of scientists and the process of science.

We believe the network made possible an effective literacy and science environment for deaf children where reading and writing became a natural conversation-like form of communication. Still, there is a great need for support if a variety of networked activities are to be developed and implemented in classrooms. Many of the science writing experiences that were possible demanded large amounts of time and people resources in the science classroom. This presents problems for science teachers, who are mandated to cover a certain scope of science content during the year and have minimal expertise as language teachers. There would be much to gain if science teachers and writing teachers could work together to plan for, implement, and assess science goals and literacy goals. New kinds of curriculum structures and ways of thinking about the disciplines need to be created, implemented, and studied in order for the connectedness of literacy and science work to be realized.

Notes

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1. The Earth Lab project capitalized on the communication features of local area network technologies to create an environment for science learning that would model the collaborative work of real scientists. On a local area network, all computers are wired together making it possible for a person at one machine to communicate and share data with a person at any other machine.

2. A measure of student's syntactical ability was determined by systematically calculating the number of corrections necessary to transform a message into acceptable standard English. As such, the measure confirms the effort that a teacher must make in order to fully understand a student and can be used to assess his/her progress.

3. All examples are in the form originally composed by students and teachers.

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Appendix 16

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